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obstructions immediately downstream from  
the turbine wheel on turbine performance

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St. Paul, Minnesota; University of Minnesota

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AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTIONS  
IMMEDIATELY DOWNSTREAM FROM THE TURBINE WHEEL  
ON TURBINE PERFORMANCE

A Thesis  
Submitted to the Graduate Faculty  
of the  
University of Minnesota

by  
R. B. SPENCER

In Partial Fulfillment of the Requirements  
for the  
Degree of  
Master of Science  
in  
Aeronautical Engineering  
(Power Plants)

August

1949



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University of Minnesota

20 August 1949

R. B. Spencer



# AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTION IMMEDIATELY DOWNSTREAM FROM THE TURBINE EXHAUST ON TURBINE PERFORMANCE

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AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTIONS  
IMMEDIATELY DOWNSTREAM FROM THE TURBINE WHEEL ON  
TURBINE PERFORMANCE

SUMMARY

An investigation was conducted on obstructions in the tail pipe of a B-33 Turbosupercharger in order to determine their influence upon the performance of the turbine wheel. The obstructions were located down stream of the turbine wheel at stations varying from  $9/16$  inch to 3.0 inches. At each station the turbosupercharger was run at speeds varying from 10,000 to 20,000 revolutions per minute. The expansion ratios across the turbine varied from 1.15 to 1.70. At each speed the turbine input power and the compressor input power were measured. The efficiencies were computed by the ratio of compressor power to turbine power.

Two types of obstructions were employed. One was a set of four  $1\frac{1}{2}$  inches in diameter rods  $2\frac{1}{2}$  inches long, and the other was a set of four sectors with a 7 inch outer radius and a  $\frac{1}{4}$  inch inner radius. Each sector was  $\frac{1}{2}$  inch thick.

At the speeds, expansion ratios, and the air flows used in this investigation no change in turbine performance was observed.



AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTION  
IMMEDIATELY DOWNSTREAM FROM THE TURBINE WHEEL ON  
TURBINE PERFORMANCE

INTRODUCTION

This project was conducted to determine the influence of obstructions immediately downstream from the turbine wheel upon the performance of the turbine. Two types of obstructions were employed in this investigation. The distance from the turbine wheel at which the obstructions were located was varied as well as the speed and the expansion ratio of the turbine. The effect of these obstructions was obtained by computing the efficiency from the turbine power input.

This project was instigated by the desire to know whether obstructions would influence the performance of a gas turbine and the amount of the influence. In gas turbine design the tail pipe lends itself readily to the adaptation of preheaters, regenerators, and other heat absorbing devices. Also, in certain type jet engines employing variable tail pipe nozzles, the mechanism which controls the variable nozzle is located within the tail pipe. In turbopropeller design it would be advantageous to divide the exhaust pipe or to bend the flow of the exhaust. In employing after



burning the after burners are located within the tail pipe. In any of the foregoing citations what is done is equivalent to obstructing the tail pipe. Therefore this investigation has contributed to advancing the design of turbojet and gas turbine engines.

This investigation was not conducted to check or to determine the performance of a gas turbine, nor was it instrumented to do so. The turbine employed was instrumented only to determine the power input and output at existing ambient conditions.



# AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTIONS IMMEDIATELY DOWNSTREAM FROM THE TURBINE INLET ON TURBINE PERFORMANCE

## EQUIPMENT AND PROCEDURE

The turbosupercharger used in this investigation was a B-33, manufactured by the Allis-Chalmers Company under license from the General Electric Company. The compressor was rated at 120 pounds of air per minute at an altitude of 2,800 feet and at a speed of 24,000 revolutions per minute. The turbine was a single stage impulse turbine with all the pressure drop occurring across the nozzles. The turbine air was supplied by the supercharger of an Allison V-1710 aircraft engine. The Allison engine was naturally aspirated. A Junko 004 type combustion chamber was attached to the turbine and the air from the Allison engine was burned to approximately 1775 degrees Rankine before entering the turbine. The best operating expansion ratio for the turbine was used between 3 and 4, with the waste gate partially opened depending on the power required by it. In this investigation the waste gate was sealed closed.

Ambient air from outside the laboratory was drawn in by the compressor, compressed, and then discharged back outside the building. The air used for the turbine



was picked up inside the test cell, compressed in the supercharger of the Allison engine, passed through the combustion chamber, through the turbine and then discharged outside the building.

The tail pipe used was manufactured at the metal shop of the University of Minnesota and was constructed of stainless steel. The tail pipe consisted of an inner and an outer pipe. The outer pipe was 14 inches in diameter. It was provided with a flange so that it could be bolted to the turbine discharge flange. It was also provided with four equally spaced longitudinal slots 10 inches long and  $3/8$  inches wide. These slots were used to position the obstructions in the tail pipe. The inner pipe consisted of a cylindrical pipe 9 inches in diameter and one foot long to which was welded a cone one foot long. The inner pipe was held rigidly in place by three struts two inches in diameter. These struts were 14 inches from the turbine wheel. One strut was adapted to pass cooling air to the inside of the inner pipe. The air passed upstream from this strut and impinged upon the downstream side of the turbine wheel. The cooling air was forced in at about ten pounds per minute. The cooling air was picked up inside the test cell.

The forward ten inches of the tail pipe was the test section. The test obstructions were placed transversally between the inner and the outer pipes. When



the obstructions were in place, the slots in the outer pipe were closed by four plates  $1\frac{1}{4}$  inches long and two inches wide. The plates were curved to conform to the contours of the outer pipe. The forward ends of the slots were drilled for a  $\frac{1}{4}$  inch stud. The stud was passed through the hole in the plate, through the slot, and then screwed into the test obstruction. This provided the means of securely holding the obstruction in place. The after end of the plates were held in place by a metal clamp which passed all the way around the tail pipe. Separate plates were used for each test location.

Two types of obstructions were employed. One type was four  $1\frac{1}{4}$  inch diameter rods  $2\frac{1}{2}$  inches long. The ends of the rods were shaped to conform to the contours of the inner and outer pipes. The ends which fitted against the outer pipe were drilled and tapped for a  $\frac{1}{4}$  inch stud. The other type was four 30 degree sectors with a seven inch outside radius and a  $4\frac{1}{2}$  inch inside radius. Each sector was  $\frac{1}{2}$  inch thick and when all four sectors were in place one-third of the tail pipe was obstructed. The outside edge of the sectors were drilled and tapped to accommodate the  $\frac{1}{4}$  inch studs. These studs were used to hold the test obstructions in place as described above.

The  $1\frac{1}{4}$  inch diameter rods were used first in this investigation. They were placed first at a distance of three inches downstream of the turbine wheel and



then were moved upstream at one inch increments. At each station the turbine was run at 10,000, 12,000, 14,000, 16,000, 18,000, and 20,000 revolutions per minute. At each station and each speed the power input to both the compressor and the turbine was measured. The turbine efficiency was computed by dividing the compressor power by the turbine power. At one inch from the turbine wheel it was observed that no effect from the obstructions existed and at this time the study was started on the sector obstructions. The sectors were placed as close to the turbine wheel as possible which was  $9/16$  inch. This distance was limited by a flange around the turbine discharge which protruded  $9/16$  inch from the turbine wheel. It was also felt that any closer distance would endanger the turbine wheel in case of vibrations being set up in the obstructions. On the run at  $9/16$  inch from the turbine wheel two bolts securing the tail pipe to the turbine backed out.

The following is a list of runs that were made. Each set of runs was made at 10,000, 12,000, 14,000, 16,000, 18,000, and 20,000 revolutions per minute.

| <u>Set No.</u> | <u>Type Obstructions</u> | <u>Location</u> |
|----------------|--------------------------|-----------------|
| 1              | None                     | None            |
| 2              | $1\frac{1}{4}$ inch rods | 3.0 inches      |
| 3              | $1\frac{1}{4}$ inch rods | 2.0 inches      |
| 4              | $1\frac{1}{4}$ inch rods | 1.0 inches      |
| 5              | None                     | None            |



| <u>Set No.</u> | <u>Type Obstructions</u> | <u>Location</u> |
|----------------|--------------------------|-----------------|
| 6              | 30 degree sectors        | 9/16 inches     |
| 7              | 30 degree sectors        | 1.0 inches      |
| 8              | 30 degree sectors        | 9/16 inches     |

List of test equipment:

1. R-33 Turbosupercharger  
Manufactured by Allis-Chalmers under contract from the General Electric Company.
2. Jumo 004 Combustion Chamber  
Manufactured in Germany for the Jumo 0004 Turbojet engine.
3. Fuel Pump Motor  
Manufactured by the Siman Company.
4. Fuel Pump  
Manufactured by the Vickers Inc., Company.
5. Ignition Coil and Spark Plug  
Made in Germany for the Jumo 004 engine.
6. Acetylene Supply.
7. Allison V 1710 aircraft engine, naturally aspirated.
8. Allison V 1710 supercharger.



# AN EXPERIMENTAL STUDY OF THE EFFECTS OF OBSTRUCTIONS IMMEDIATELY DOWNSTREAM FROM THE TURBINE WHEEL ON TURBINE PERFORMANCE

## INSTRUMENTATION

The instruments used in this investigation were previously installed and supplied by the University of Minnesota. No effort was made to calibrate these instruments. The measurements taken were not to determine the performance of the turbosupercharger, but rather to measure variations in the performance. The instruments used were considered adequate to conduct this investigation.

The air flow to the turbine was measured by a 5.6 inch diameter flat plate orifice in an eight inch pipe. Flush type pick-ups were used to measure the differential pressure. One was located eight inches upstream of the orifice and the other was located four inches downstream of the orifice. This differential pressure was read on a six inch inclined Mercury Manometer which could be read to the nearest five hundredths of an inch. This orifice was previously calibrated and was assumed accurate throughout the investigation. The air flow to the compressor was measured by a seven inch diameter orifice. This orifice as well as the calibration charts



were obtained from the Packard Motor Car Company, Aircraft Engine Division. The differential pressure was read on a 20 inch water vertical manometer. This orifice was previously calibrated and was assumed accurate throughout the investigation.

The temperatures of the air flows through both orifices were measured by a self balancing potentiometer used with an iron constantan thermocouple. The self balancing potentiometer was manufactured by the Brown Instrument Company, and hereinafter is referred to as a Brown Box. This instrument could be read to the nearest five degrees Fahrenheit. Hence, measurements taken at low temperatures are subjected to more error percentage wise than temperatures of a higher order.

The fuel flow was measured with a Stabil vis Rotameter manufactured by the Fisher Porter Company. This instrument was designed for a diesel fuel of specific gravity of .862. The fuel used in this investigation was a fuel oil and its specific gravity did not vary over five per cent from that for which the instrument was designed.

Temperatures were measured at the compressor inlet and outlet, and at the turbine inlet and outlet. These temperatures were measured with the Brown Box. To measure the turbine inlet temperature a chromel alumel thermocouple was used. This thermocouple was located one-quarter the distance around the nozzle box from the



turbine air inlet. This location was chosen in order to keep the thermocouple out of the direct flame from the combustion chamber. A calibration chart for the use of the chromel alumel thermocouple is appended to this report. The other temperatures were measured with the Crown Box using 20 gauge iron constantan thermocouples.

### List of instruments:

#### Manometers

1.  $P_{c1}$  Mercury Barometer
2.  $P_2$  Aneroid 10- 54 inches Mercury
3.  $P_3$  Vertical 57 inches Mercury
4.  $P_{t1}$  Aneroid 10- 54 inches Mercury
5.  $P_{t4}$  Vertical 70 inches Mercury
6.  $\Delta P_c$  Vertical 20 inches water
7.  $\Delta P_t$  Inclined 6 inches Mercury

#### Temperatures

8.  $T_{c1}$  Bare I C thermocouple
9.  $T_2$  Bare I C thermocouple
10.  $T_3$  Bare I C thermocouple
11.  $T_{t1}$  Bare I C thermocouple
12.  $T_{t4}$  Shielded G A thermocouple

#### Tachometer

13. Turbine RPM Synchronous motor 0-35,000 RPM



# AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTIONS IMMEDIATELY DOWNSTREAM FROM THE TURBINE NOZZLE ON TURBINE PERFORMANCE

## RESULTS AND DISCUSSION

The results of this investigation are found in Tables XIII through XVII and Figures 7 through 9. The obstructions used in this investigation produced negligible results on the turbine performance. The computed changes in turbine efficiency are erratic and variable. However, the overall trend is to show that no change in efficiency when as much as one-third of the tail pipe was obstructed. The erratic readings are a direct result of the irregular output of the Allison supercharger. At the low manifold pressures used on the Allison engine during the investigation it was impossible to maintain steady operating conditions on this engine. Its speed would vary as much as 200 revolutions per minute for a fixed throttle setting. Consequently, the supercharger was varying and surging in its output. This surging caused uneven burning of the air in the combustion chamber which caused temperature variations at the nozzle block. The total entrance temperature to the turbine is believed to be in considerable error due to the surging of the Allison supercharger.



When the turbosupercharger was running at 20,000 revolutions per minute the Allison engine was running near its maximum rated speed. Above 18,000 revolutions per minute on the turbosupercharger it was impossible to cool the Allison engine and its oil. This was due to an inadequate cooling water supply. The data taken at 18,000 and 20,000 revolutions per minute was taken very quickly and during changing conditions. Consequently, the data at these speeds are questionable.

The maximum efficiency of the turbine at its rated air flow occurs at an expansion ratio of about three. The maximum expansion ratio reached in this study was 1.70. Higher values could not be obtained because of the limitations of the Allison engine and its supercharger. If higher values could have been obtained this investigation would have been more complete in its scope.

The efficiency as obtained by this study are unreliable. As stated previously the total entrance temperature is believed to be in error. Since efficiency is an inverse function of this temperature, a variation in this temperature will cause an inverse variation in the efficiency. However, this investigation was conducted to measure differences in efficiencies only, and the differences should be accurate within experimental accuracy.



# AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTIONS IMMEDIATELY DOWNSTREAM FROM THE TURBINE WHEEL ON TURBINE PERFORMANCE

## CONCLUSION

This investigation has shown that obstructions placed in the tail pipe of a gas turbine has negligible effect upon the efficiency of the turbine. Large obstructions placed relatively close to the turbine wheel showed no noticeable change in the turbine efficiency.

It is recommended that further study be made on this project, employing a different type tail pipe and a different type method of measuring the turbine power output. It is suggested that a tail pipe be used whose outside diameter is the same as the outside diameter of the turbine wheel, and that the inside pipe have the same diameter as the root circle of the turbine blading. Such a tail pipe will prevent any expansion of the exhaust gases between the turbine wheel and the obstructions. This type pipe would also maintain higher velocities around the obstructions in the tail pipe. It is further recommended that some type of dynamometer be used to absorb the turbine power rather than its compressor. This would eliminate temperature and pressure errors in the computation of the power.



AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTIONS  
IMMEDIATELY DOWNSTREAM FROM THE TURBINE WHEEL ON  
TURBINE PERFORMANCE

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# AN EXPERIMENTAL STUDY OF THE INFLUENCE OF OBSTRUCTIONS INITIALLY DOWNSTREAM FROM THE TURBINE NOZZLE ON TURBINE PERFORMANCE

## FORMULA

### 1. Table of Symbols.

|              |                                                                                       |
|--------------|---------------------------------------------------------------------------------------|
| $P_{c1}$     | Static pressure of the compressor measuring orifice.<br>(inches of Mercury)           |
| $P_2$        | Static pressure of compressor inlet. (inches of<br>mercury relative)                  |
| $P_3$        | Static pressure at discharge of compressor. (inches<br>of Mercury relative)           |
| $P_{t1}$     | Static pressure of the turbine measuring orifice.<br>(inches of Mercury relative)     |
| $\Delta P_c$ | Differential pressure across the compressor measur-<br>ing orifice. (inches of water) |
| $\Delta P_t$ | Differential pressure across the turbine measuring<br>orifice. (inches of Mercury)    |
| $P_{t4}$     | Total pressure at turbine entrance. (inches of<br>Mercury)                            |
| $P_{t5}$     | Total pressure at turbine exit. (inches of Mercury)                                   |
| $T_{c1}$     | Temperature at the compressor measuring orifice.<br>(degrees Rankine)                 |
| $T_2$        | Temperature at compressor inlet. (degrees Rankine)                                    |
| $T_3$        | Temperature at compressor exit. (degrees Rankine)                                     |
| $T_{t1}$     | Temperature at the turbine measuring orifice.<br>(degrees Rankine)                    |
| $T_{t4}$     | Total temperature at turbine inlet. (degrees<br>Rankine)                              |
| $T_{t5}$     | Total temperature at turbine exit. (degrees<br>Rankine)                               |



$W_c$  Air flow through the compressor. (pounds per minute)

$W_t$  Air flow through the turbine. (pounds per minute)

$L_c$  Power input to the compressor. (B.T.U. per minute)

$L_t$  Power input to the turbine. (B.T.U. per minute)

B.T.U. British Thermal Unit.

$\gamma$  Ratio of specific heat at constant pressure to specific heat at constant volume.

$\eta_t$  Turbine efficiency.

$h_t$  Total enthalpy.

$q$  Heat added.

$w$  Work.

$g$  Acceleration of gravity.

$J$  Mechanical equivalent of heat.

$C_p$  Specific heat at constant pressure.

$c$  Theoretical spouting velocity. (feet per second)

## 2. Power and Efficiency.

$$L_c = W_c C_p T_{T2} \frac{T_{T3} - T_{T2}}{T_{T2}}$$

$$L_t = W_t C_p T_{T4} \left[ 1 - \frac{1}{\left( \frac{P_{T4}}{P_{T5}} \right)^{\frac{\gamma-1}{\gamma}}} \right]$$

$$\eta_t = \frac{L_c}{L_t}$$

## 3. Spouting Velocity.

$$c = \sqrt{2 C_p T_{T4} \left[ 1 - \frac{1}{\left( \frac{P_{T4}}{P_{T5}} \right)^{\frac{\gamma-1}{\gamma}}} \right]}$$





Plate I. Brown Self Balancing Potentiometer.



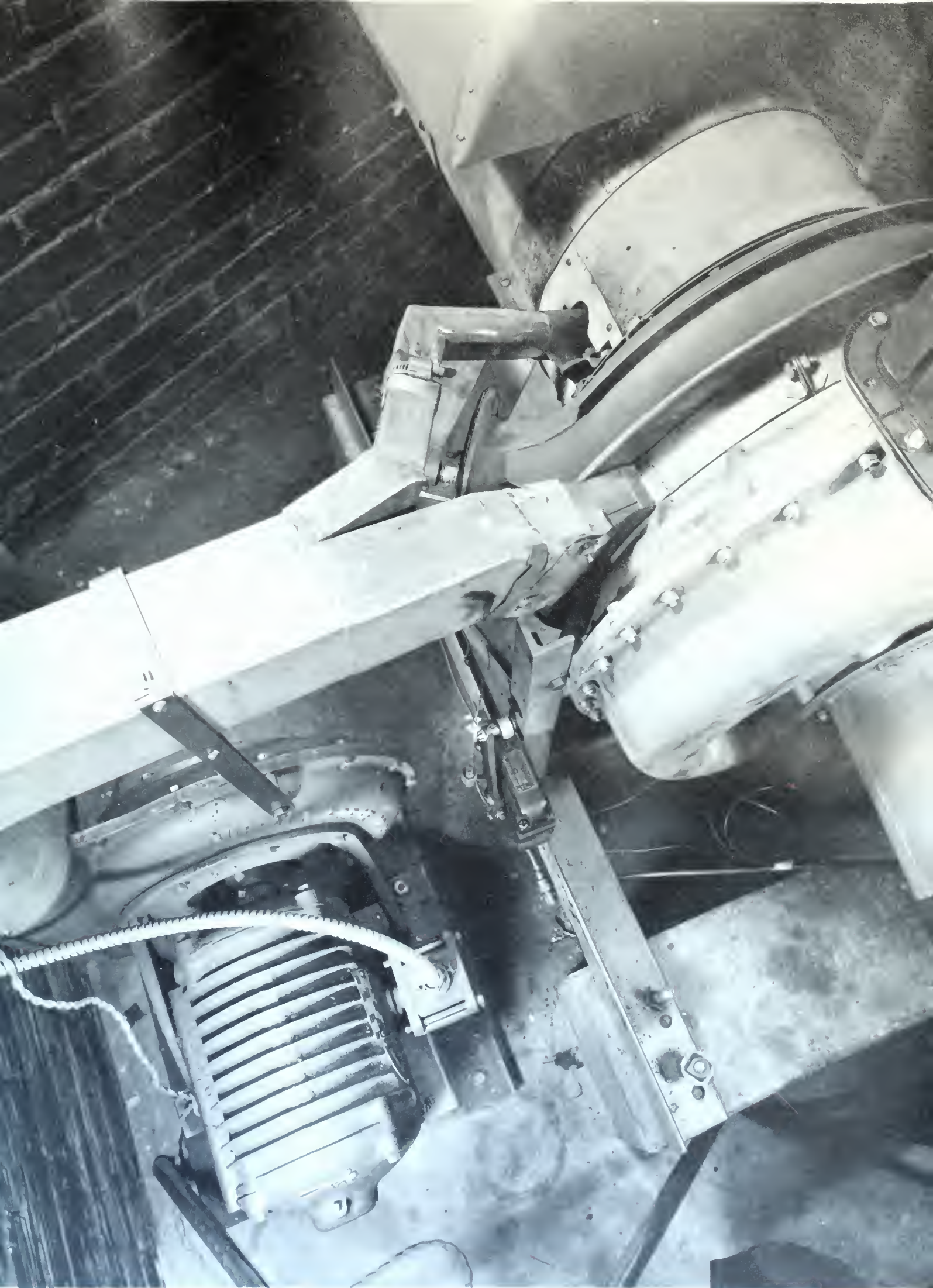


Plate I . Cooling Air Fan, Motor, and Ducting.



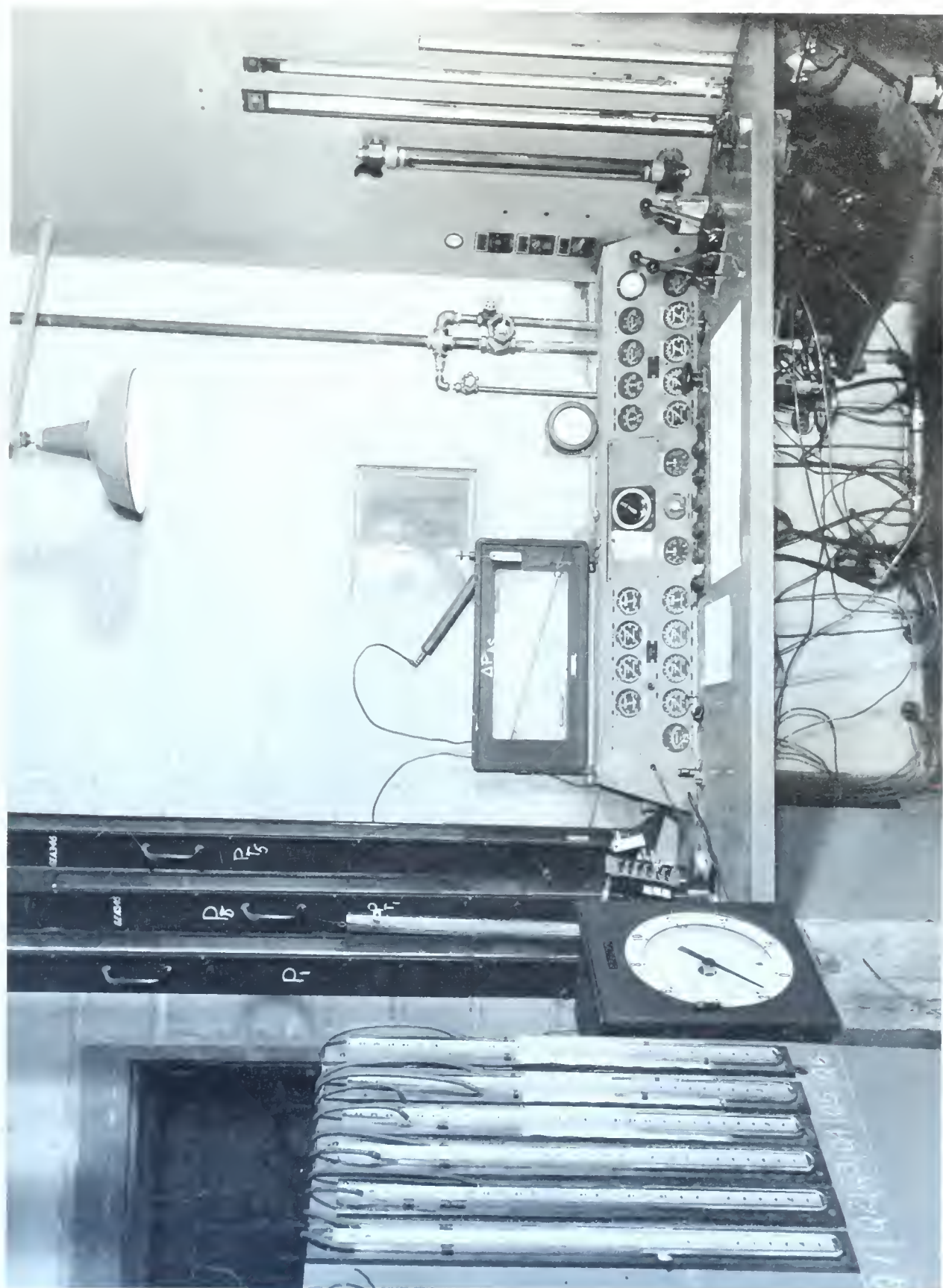


Plate III. Instrument Panel.





Fig. 1. Turbine Inlet Instrumentation





Plate V. Compressor Inlet Instrumentation.



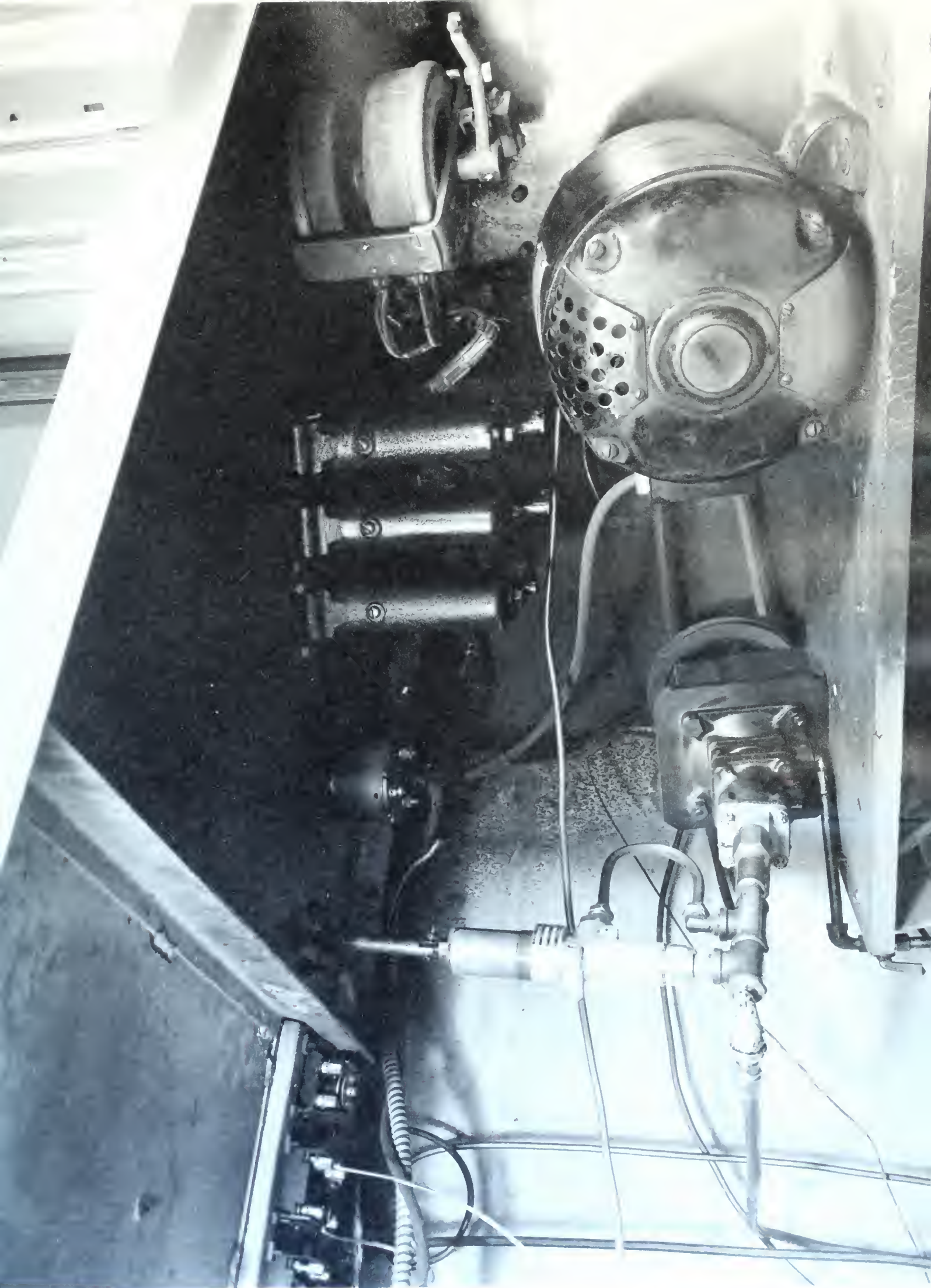


Plate 11. Turbine Fuel Tank, Motor, and Control Valve





Plate VII. Compressor Measuring Orifice.





Plate VIII. Tail Pipe with Obstructions.



TABLE I

TEST DATA

19 JULY 1949

NO OBSTRUCTIONS

BAROMETER 29.08 in.

| Run No.               | 19     | 20     | 21     | 22     | 23     | 24     |
|-----------------------|--------|--------|--------|--------|--------|--------|
| RPM                   | 20,000 | 15,000 | 16,000 | 12,000 | 16,000 | 14,000 |
| $T_{cl}^{\circ}R$     | 29.0   | 29.4   | 29.2   | 29.3   | 29.3   | 29.3   |
| $T_{cl}^{\circ}R$     | 19.3   | 5.4    | 16.5   | 7.3    | 12.5   | 9.6    |
| $T_{05}^{\circ}R$     | 29.03  | 29.03  | 29.03  | 29.03  | 29.03  | 29.03  |
| $\Delta T_c^{\circ}R$ | 1.75   | .96    | 1.40   | .64    | 1.10   | .87    |
| $T_{cl}^{\circ}R$     | 29.08  | 29.03  | 29.03  | 29.03  | 29.03  | 29.03  |
| $\Delta T_c^{\circ}R$ | 1.64   | 1.00   | 1.64   | 1.30   | 1.43   | 1.37   |
| $T_{cl}^{\circ}F$     | 810    | 152    | 200    | 175    | 197    | 188    |
| $T_{cl}^{\circ}F$     | 1312   | 1312   | 1312   | 1312   | 1312   | 1312   |
| $T_{cl}^{\circ}F$     | 60     | 60     | 60     | 60     | 60     | 60     |
| $T_{02}^{\circ}F$     | 65     | 63     | 70     | 70     | 72     | 72     |
| $T_{03}^{\circ}F$     | 750    | 185    | 230    | 150    | 203    | 180    |
| Fuel flow<br>g/min.   | 130    | 83     | 126    | 96     | 113    | 104    |



TABLE II

TEST DATA

19 JULY 1949

1½" NO. OBSTRUCTIONS AT 3.0"

MANOMETER 29.06

| Run No.               | 25     | 26     | 27     | 28     | 29     | 30     |
|-----------------------|--------|--------|--------|--------|--------|--------|
| RPM                   | 20,000 | 10,000 | 18,000 | 12,000 | 16,000 | 14,000 |
| Pt1" Hg               | 29.1   | 29.4   | 29.2   | 29.4   | 29.2   | 29.3   |
| Pt4" Hg               | 20.5   | 5.4    | 15.0   | 7.4    | 12.5   | 9.6    |
| Pt5" Hg               | 29.06  | 29.06  | 29.06  | 29.0   | 29.06  | 29.06  |
| ΔPt" Hg               | 1.8    | .50    | 1.40   | .65    | 1.10   | .94    |
| Pc1" Hg               | 29.06  | 29.06  | 29.06  | 29.06  | 29.06  | 29.06  |
| ΔPc" H <sub>2</sub> O | 1.33   | 1.00   | 1.65   | 1.23   | 1.40   | 1.30   |
| Tt1°F                 | 200    | 165    | 200    | 182    | 200    | 195    |
| Tt4°F                 | 1312   | 1312   | 1312   | 1312   | 1313   | 1312   |
| Tc1°F                 | 60     | 60     | 60     | 60     | 60     | 60     |
| Tt2°F                 | 67     | 63     | 70     | 70     | 70     | 72     |
| Tt3°F                 | 260    | 125    | 230    | 150    | 200    | 130    |
| Fuel flow<br>#/min.   | 136    | 82     | 123    | 92     | 110    | 102    |



TABLE III

TEST DATA

21 JULY 1949

1 1/2" DIAMETER RODS AT 2.0"

BAROMETER 29.00

| Run No.                        | 31     | 32     | 33     | 34     | 35     | 36     |
|--------------------------------|--------|--------|--------|--------|--------|--------|
| RPM                            | 10,000 | 20,000 | 12,000 | 18,000 | 14,000 | 16,000 |
| $P_{t1}$ "Hg                   | 20.35  | 21.05  | 21.30  | 21.15  | 29.30  | 29.25  |
| $P_{t4}$ "Hg                   | 5.3    | 19.8   | 7.3    | 15.5   | 9.5    | 12.5   |
| $P_{t5}$ "Hg                   | 29.00  | 29.00  | 29.00  | 29.00  | 29.00  | 29.00  |
| $\Delta P_t$ "Hg               | .46    | 1.66   | .66    | 1.38   | .85    | 1.12   |
| $P_{c1}$ "Hg                   | 29.00  | 29.00  | 29.00  | 29.00  | 29.00  | 29.00  |
| $\Delta P_c$ "H <sub>2</sub> O | 1.05   | 1.30   | 1.22   | 1.60   | 1.30   | 1.40   |
| $T_{t1}$ °F                    | 140    | 179    | 165    | 185    | 180    | 183    |
| $T_{t4}$ °F                    | 1310   | 1312   | 1312   | 1310   | 1312   | 1310   |
| $T_{c1}$ °F                    | 71     | 71     | 75     | 76     | 78     | 79     |
| $T_{t2}$ °F                    | 80     | 82     | 82     | 90     | 85     | 88     |
| $T_{t3}$ °F                    | 139    | 270    | 163    | 240    | 190    | 220    |
| Fuel flow<br>#/min.            | 83     | 139    | 92     | 123    | 79     | 110    |



TABLE IV

TEST DATA

22 JULY 1949

1/3 INCH OR TAIL PIPE  
BLOCKED AT 9/16"

BAROMETRIC 29.15

| Run No.                           | 37     | 38     | 39     | 40     | 41     | 42     |
|-----------------------------------|--------|--------|--------|--------|--------|--------|
| HPH                               | 10,000 | 12,000 | 14,000 | 16,000 | 20,000 | 18,000 |
| $P_{t1}^{\text{Hg}}$              | 27.3   | 29.3   | 29.25  | 29.20  | 29.0   | 29.1   |
| $P_{t4}^{\text{Hg}}$              | 5.6    | 8.1    | 10.5   | 12.8   | 21.1   | 15.0   |
| $P_{t5}^{\text{Hg}}$              | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  |
| $\Delta P_t^{\text{Hg}}$          | .48    | .67    | .86    | 1.10   | 1.90   | 1.40   |
| $P_{c1}^{\text{Hg}}$              | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  |
| $\Delta P_c^{\text{H}_2\text{O}}$ | 1.30   | 1.35   | 1.32   | 1.35   | 1.65   | 1.40   |
| $T_{t1}^{\text{OF}}$              | 125    | 172    | 170    | 170    | 205    | 205    |
| $T_{t4}^{\text{OF}}$              | 1312   | 1312   | 1312   | 1310   | 1310   | 1313   |
| $T_{c1}^{\text{OF}}$              | 52     | 50     | 52     | 55     | 55     | 55     |
| $T_{t2}^{\text{OF}}$              | 60     | 60     | 60     | 62     | 65     | 65     |
| $T_{t3}^{\text{OF}}$              | 115    | 140    | 164    | 195    | 260    | 230    |
| Fuel flow<br>#/min.               | 87.5   | 98     | 116    | 119    | 130    | 122    |



TABLE 7  
COMPRESSED TEST DATA

| NO OBSTRUCTIONS                               |        |        |        | COMPRESSOR |        |        |
|-----------------------------------------------|--------|--------|--------|------------|--------|--------|
| Run No.                                       | 20     | 22     | 24     | 23         | 21     | 19     |
| SPP                                           | 10,000 | 12,000 | 14,000 | 16,000     | 18,000 | 20,000 |
| $T_{T3}$                                      | 585    | 610    | 640    | 663        | 690    | 720    |
| $T_{T2}$                                      | 528    | 530    | 532    | 532        | 530    | 525    |
| $\Delta T_c$                                  | 57     | 80     | 108    | 131        | 160    | 195    |
| $\frac{\Delta T_c}{T_{T2}}$                   | .1079  | .1510  | .2025  | .2460      | .3020  | .3710  |
| $\theta_2$                                    | 1.015  | 1.020  | 1.024  | 1.024      | 1.020  | 1.010  |
| $\sqrt{\theta_2}$                             | 1.008  | 1.010  | 1.012  | 1.012      | 1.010  | 1.005  |
| $P_2$                                         | 24.08  | 22.13  | 19.73  | 17.63      | 15.63  | 13.78  |
| $\delta_2$                                    | .306   | .741   | .661   | .591       | .525   | .461   |
| $\Delta P_c$                                  | 1.00   | 1.30   | 1.30   | 1.45       | 1.68   | 1.62   |
| $P_{c1}$                                      | 29.03  | 29.03  | 29.03  | 29.03      | 29.03  | 29.03  |
| $T_{c2}$                                      | 520    | 520    | 520    | 520        | 520    | 520    |
| $\frac{\Delta P_c P_{c1}}{T_{c1}}$            | .0558  | .0726  | .0726  | .0810      | .0933  | .0905  |
| $322 \sqrt{\frac{\Delta P_t P_{t1}}{T_{c1}}}$ | 76.0   | 85.7   | 85.7   | 91.6       | 98.5   | 96.9   |
| $\frac{\sqrt{\theta_2}}{\delta_2}$            | 94.7   | 116.7  | 131.4  | 157.0      | 169.2  | 212.0  |
| $\frac{1}{\sqrt{\theta_2}}$                   | 7940   | 11900  | 13800  | 15700      | 17300  | 17900  |



TABLE VI

## CORRECTED TEST DATA

1 1/2" DIAMETER NOZZLE AT 3.0"

COMPRESSOR

| Run No.                                       | 26     | 28     | 30     | 29     | 27     | 25     |
|-----------------------------------------------|--------|--------|--------|--------|--------|--------|
| HPW                                           | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $T_{T3}$                                      | 591    | 610    | 640    | 660    | 590    | 720    |
| $T_{T2}$                                      | 527    | 530    | 532    | 530    | 530    | 527    |
| $\Delta T_c$                                  | 54     | 80     | 108    | 130    | 160    | 103    |
| $\frac{\Delta T_c}{T_{T2}}$                   | .1026  | .1510  | .2025  | .2450  | .3020  | .3660  |
| $\theta_2$                                    | 1.015  | 1.020  | 1.023  | 1.020  | 1.020  | 1.015  |
| $\sqrt{\theta_2}$                             | 1.008  | 1.010  | 1.012  | 1.010  | 1.010  | 1.008  |
| $P_2$                                         | 24.26  | 22.11  | 20.06  | 18.06  | 16.96  | 13.90  |
| $\delta_2$                                    | .311   | .739   | .671   | .601   | .566   | .467   |
| $\Delta P_0$                                  | 1.30   | 1.23   | 1.30   | 1.40   | 1.65   | 1.83   |
| $P_{c1}$                                      | 29.66  | 27.06  | 27.06  | 29.06  | 29.96  | 24.96  |
| $T_{c1}$                                      | 520    | 527    | 520    | 520    | 520    | 520    |
| $\frac{\Delta P_c P_{c1}}{T_{c1}}$            | .0557  | .0639  | .0723  | .0735  | .0924  | .1023  |
| $322 \sqrt{\frac{\Delta P_c P_{c1}}{T_{c1}}}$ | 76.0   | 84.4   | 86.7   | 89.5   | 97.8   | 103.2  |
| $\frac{\sqrt{\theta_2}}{\delta_2}$            | 34.1   | 115.5  | 130.0  | 149.7  | 179.0  | 222.0  |
| $\frac{\lambda}{\sqrt{\theta_2}}$             | 1950   | 11830  | 1332   | 15850  | 17820  | 19010  |



TABLE VII  
CONDUCTED TEST DATA

1" DIAMETER HOLES AT 2.0"

COMPRESSION

| Run No.                                   | 31     | 33     | 35     | 36     | 34     | 32     |
|-------------------------------------------|--------|--------|--------|--------|--------|--------|
| SPM                                       | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $T_{T3}$                                  | 537    | 620    | 650    | 630    | 700    | 730    |
| $T_{T2}$                                  | 540    | 542    | 545    | 550    | 542    | 540    |
| $\Delta T_c$                              | 55     | 78     | 105    | 130    | 158    | 190    |
| $\frac{\Delta T_c}{T_{T2}}$               | .1013  | .1440  | .1925  | .2365  | .2915  | .3520  |
| $\theta_2$                                | 1.033  | 1.042  | 1.049  | 1.058  | 1.042  | 1.033  |
| $\sqrt{\theta_2}$                         | 1.013  | 1.021  | 1.025  | 1.029  | 1.021  | 1.013  |
| $r_2$                                     | 24.10  | 22.40  | 20.20  | 18.00  | 16.00  | 14.00  |
| $\delta_2$                                | .806   | .750   | .75    | .602   | .535   | .468   |
| $\Delta P_c$                              | 1.05   | 1.22   | 1.30   | 1.40   | 1.50   | 1.70   |
| $T_{c1}$                                  | 29.00  | 29.00  | 29.00  | 29.20  | 29.00  | 28.00  |
| $T_{c1}$                                  | 531    | 535    | 533    | 537    | 536    | 531    |
| $\frac{\Delta T_{c1}}{T_{c1}}$            | .0572  | .0662  | .0702  | .0753  | .0865  | .0942  |
| $322 \sqrt{\frac{\Delta T_{c1}}{T_{c1}}}$ | 77.0   | 82.9   | 85.4   | 88.4   | 94.5   | 101.2  |
| $\frac{\sqrt{\theta_2}}{\delta_2}$        | 127.0  | 113.0  | 129.5  | 151.0  | 180.0  | 220.0  |
| $\frac{r_2}{\sqrt{\theta_2}}$             | 1850   | 11730  | 13650  | 15450  | 17600  | 19650  |



TABLE VIII

COMBUSTION TEST DATA

1/3 INCH OR LARGER PIPE BURNED AT 9/16" COMPRESSION

| Run No.                                       | 37     | 38     | 39     | 40     | 42     | 41     |
|-----------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPV                                           | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $T_{m3}$                                      | 575    | 600    | 624    | 655    | 690    | 720    |
| $T_{T2}$                                      | 520    | 520    | 520    | 522    | 525    | 525    |
| $\Delta T_c$                                  | 55     | 80     | 104    | 133    | 175    | 195    |
| $\frac{\Delta T_c}{T_{T2}}$                   | .1058  | .1536  | .2000  | .2545  | .3335  | .3715  |
| $\theta_2$                                    | 1.000  | 1.000  | 1.000  | 1.005  | 1.005  | 1.005  |
| $\sqrt{\theta_2}$                             | 1.000  | 1.000  | 1.000  | 1.003  | 1.003  | 1.003  |
| $P_2$                                         | 24.35  | 22.85  | 19.65  | 17.55  | 15.45  | 13.45  |
| $\delta_2$                                    | .315   | .260   | .257   | .287   | .246   | .250   |
| $\Delta P_c$                                  | 1.00   | 1.25   | 1.32   | 1.35   | 1.40   | 1.65   |
| $P_{c1}$                                      | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  |
| $T_{c1}$                                      | 512    | 512    | 512    | 515    | 515    | 515    |
| $\frac{\Delta P_c P_{c1}}{T_{c1}}$            | .0569  | .0711  | .0751  | .0763  | .0792  | .0932  |
| $322 \sqrt{\frac{\Delta P_c P_{c1}}{T_{c1}}}$ | 76.7   | 86.0   | 88.3   | 89.0   | 90.6   | 93.5   |
| $\frac{\sqrt{\theta_2}}{\delta_2}$            | 74.7   | 112.5  | 134.1  | 152.0  | 176.0  | 219.5  |
| $\frac{P_2}{\sqrt{\theta_2}}$                 | 13000  | 12000  | 14000  | 15950  | 17700  | 19700  |



TABLE IX  
CORROTOR TEST DATA

NO OBSTRUCTIONS

TURBINE

| Run No.                                      | 20     | 22     | 24     | 23     | 21     | 19     |
|----------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPM                                          | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $T_{t4}$                                     | 1772   | 1772   | 1772   | 1772   | 1772   | 1772   |
| $\phi_4$                                     | 3.41   | 3.41   | 3.41   | 3.41   | 3.41   | 3.41   |
| $\sqrt{\phi_4}$                              | 1.850  | 1.850  | 1.850  | 1.850  | 1.850  | 1.850  |
| $P_{t4}$                                     | 34.48  | 36.33  | 38.68  | 41.53  | 45.58  | 48.88  |
| $\delta_4$                                   | 1.155  | 1.235  | 1.295  | 1.392  | 1.528  | 1.635  |
| $P_{t5}$                                     | 29.03  | 29.03  | 29.03  | 29.03  | 29.03  | 29.03  |
| $\frac{P_{t4}}{P_{t5}}$                      | 1.187  | 1.275  | 1.363  | 1.460  | 1.567  | 1.675  |
| $\Delta P_6$                                 | .31    | .52    | .75    | .98    | 1.28   | 1.64   |
| $P_{t1}$                                     | 25.73  | 23.72  | 23.66  | 23.60  | 23.54  | 23.48  |
| $T_{t1}$                                     | 612    | 635    | 643    | 657    | 660    | 670    |
| $\frac{\Delta P_{t' t1}}{T_{t1}}$            | .0155  | .0235  | .0331  | .0427  | .0553  | .0690  |
| $125 \sqrt{\frac{\Delta P_{t' t1}}{T_{t1}}}$ | 70.0   | 86.3   | 102.5  | 116.5  | 132.5  | 148.1  |
| $\frac{\sqrt{\phi_4}}{\delta_4}$             | 112.2  | 129.2  | 147.4  | 154.3  | 160.5  | 163.5  |
| $\frac{1}{\sqrt{\phi_4}}$                    | 5400   | 5430   | 7256   | 8650   | 9730   | 10800  |



TABLE A

CORRECTED TEST DATA

1" DIAMETER HOLES AT 3.00

TURBINE

| Run No.                                       | 20     | 23     | 30     | 29     | 27     | 25     |
|-----------------------------------------------|--------|--------|--------|--------|--------|--------|
| AP <sub>t</sub>                               | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| T <sub>pt1</sub>                              | 1772   | 1772   | 1772   | 1772   | 1772   | 1772   |
| θ <sub>4</sub>                                | 3.41   | 3.41   | 3.41   | 3.42   | 3.41   | 3.41   |
| $\sqrt{\theta_4}$                             | 1.850  | 1.850  | 1.850  | 1.852  | 1.850  | 1.850  |
| P <sub>T4</sub>                               | 34.46  | 36.46  | 38.66  | 41.56  | 44.06  | 49.56  |
| f <sub>4</sub>                                | 1.151  | 1.220  | 1.293  | 1.390  | 1.472  | 1.660  |
| P <sub>T5</sub>                               | 27.06  | 27.06  | 29.06  | 29.06  | 27.06  | 27.06  |
| $\frac{P_{T4}}{P_{T5}}$                       | 1.187  | 1.240  | 1.283  | 1.430  | 1.643  | 1.833  |
| ΔP <sub>t</sub>                               | .35    | .50    | .69    | .95    | 1.25   | 1.45   |
| P <sub>t1</sub>                               | 28.76  | 28.70  | 28.64  | 28.58  | 28.52  | 28.46  |
| T <sub>t1</sub>                               | 655    | 642    | 655    | 660    | 660    | 660    |
| $\frac{\Delta P_t P_{t1}}{T_{t1}}$            | .0161  | .0224  | .0302  | .0412  | .0540  | .0712  |
| $325 \sqrt{\frac{\Delta P_t P_{t1}}{T_{t1}}}$ | 71.4   | 84.0   | 97.3   | 114.0  | 130.8  | 150.0  |
| $\frac{\sqrt{\theta_4}}{f_4}$                 | 114.2  | 127.4  | 139.5  | 152.0  | 164.0  | 167.0  |
| $\frac{1}{\sqrt{\theta_4}}$                   | 5400   | 6490   | 8560   | 8650   | 9740   | 10300  |



TABLE XI

COMBUSTION TEST DATA

1" DIAMETER RODS AT 2.00

TURBINE

| Run No.                                       | 31     | 33     | 35     | 36     | 34     | 32     |
|-----------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPM                                           | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $T_{t4}$                                      | 1763   | 1772   | 1772   | 1772   | 1772   | 1810   |
| $\theta_4$                                    | 3.39   | 3.41   | 3.41   | 3.41   | 3.41   | 3.48   |
| $\sqrt{\theta_4}$                             | 1.840  | 1.850  | 1.850  | 1.850  | 1.850  | 1.861  |
| $P_{t4}$                                      | 34.30  | 36.30  | 38.50  | 41.50  | 44.50  | 48.00  |
| $f_4$                                         | 1.147  | 1.215  | 1.283  | 1.390  | 1.440  | 1.633  |
| $P_{t5}$                                      | 29.00  | 29.00  | 29.00  | 29.00  | 29.00  | 29.00  |
| $\frac{P_{t4}}{P_{t5}}$                       | 1.182  | 1.252  | 1.331  | 1.434  | 1.553  | 1.687  |
| $\Delta P_t$                                  | .33    | .53    | .72    | .97    | 1.25   | 1.53   |
| $P_{t1}$                                      | 29.70  | 29.64  | 29.53  | 29.52  | 29.46  | 29.40  |
| $T_{t1}$                                      | 600    | 625    | 640    | 643    | 655    | 630    |
| $\frac{\Delta P_t P_{t1}}{T_{t1}}$            | .0153  | .0423  | .0322  | .0426  | .0543  | .0680  |
| $325 \sqrt{\frac{\Delta P_t P_{t1}}{T_{t1}}}$ | 70.0   | 87.0   | 101.0  | 116.2  | 131.0  | 146.0  |
| $\frac{\sqrt{\theta_4}}{f_4}$                 | 113.5  | 133.8  | 145.1  | 154.0  | 164.0  | 167.9  |
| $\frac{N}{\sqrt{C_1}}$                        | 5430   | 6480   | 7570   | 8650   | 9730   | 10700  |



TABLE XII

CONNECTED TEST DATA

1/3 SECTION OF TAIL PIPE BLOCK D AT 9/16"

TURBINE

| Run No.                                       | 37     | 38     | 39     | 40     | 42     | 41     |
|-----------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPM                                           | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $T_{T4}$                                      | 1772   | 1772   | 1772   | 1764   | 1735   | 1764   |
| $\theta_4$                                    | 3.41   | 3.41   | 3.41   | 3.39   | 3.43   | 3.39   |
| $\sqrt{\theta_4}$                             | 1.850  | 1.850  | 1.850  | 1.840  | 1.855  | 1.840  |
| $P_{T4}$                                      | 34.75  | 37.25  | 37.65  | 41.95  | 44.95  | 50.25  |
| $\phi_4$                                      | 1.162  | 1.245  | 1.327  | 1.444  | 1.504  | 1.600  |
| $P_{T5}$                                      | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  | 29.15  |
| $\frac{P_{T4}}{P_{T5}}$                       | 1.193  | 1.279  | 1.362  | 1.443  | 1.551  | 1.668  |
| $\Delta P_t$                                  | .33    | .52    | .71    | .95    | 1.25   | 1.80   |
| $P_{t1}$                                      | 21.85  | 21.79  | 21.73  | 21.67  | 21.61  | 21.55  |
| $T_{t1}$                                      | 585    | 632    | 630    | 650    | 665    | 665    |
| $\frac{\Delta P_t P_{t1}}{T_{t1}}$            | .0163  | .0273  | .0324  | .0419  | .0533  | .0772  |
| $525 \sqrt{\frac{\Delta P_t P_{t1}}{T_{t1}}}$ | 71.3   | 86.6   | 101.1  | 115.0  | 130.5  | 150.5  |
| $\sqrt{\frac{\Delta P_t}{\phi_4}}$            | 114.0  | 123.7  | 131.1  | 150.5  | 159.3  | 171.5  |
| $\frac{1}{\sqrt{\phi_4}}$                     | 5400   | 6400   | 7565   | 8650   | 9730   | 10800  |



TABLE XIII  
COMPUTED EFFICIENCY

20 INSTRUCTIONS

| Run No.                                   | 20     | 22     | 24     | 23     | 21     | 19     |
|-------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPM                                       | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $W_c$                                     | 76.0   | 85.7   | 95.7   | 91.6   | 98.5   | 96.9   |
| $T_{T2}$                                  | 528    | 530    | 532    | 532    | 530    | 525    |
| $C_p T_{T2}$                              | 126.8  | 127.1  | 127.8  | 127.8  | 127.1  | 126.6  |
| $\frac{\Delta T_c}{T_{T2}}$               | .1079  | .1510  | .2025  | .2460  | .3020  | .3710  |
| $I_c$                                     | 1039.0 | 1645.0 | 2215.0 | 2375.0 | 3840.0 | 4530.0 |
| $W_t$                                     | 70.0   | 86.3   | 102.5  | 116.5  | 132.5  | 148.7  |
| $T_{T4}$                                  | 1772   | 1772   | 1772   | 1772   | 1772   | 1772   |
| $C_p T_{T4}$                              | 482.0  | 482.0  | 482.0  | 482.0  | 482.0  | 482.0  |
| $1 - \frac{1}{P_{RT}^{\frac{2}{\gamma}}}$ | .0415  | .0580  | .0737  | .0889  | .1063  | .1150  |
| $L_t$                                     | 1400.0 | 2610.0 | 3645.0 | 5050.0 | 6800.0 | 8250.0 |
| $\eta_t$                                  | 74.3   | 68.3   | 62.5   | 56.9   | 56.4   | 54.9   |

$$C_p T_{T4} \left[ 1 - \frac{1}{P_{RT}^{\frac{2}{\gamma}}} \right] \begin{matrix} 20.0 & 27.9 & 35.5 & 42.8 & 51.3 & 55.4 \end{matrix}$$

$$22.4 \sqrt{C_p T_{T4} \left[ 1 - \frac{1}{P_{RT}^{\frac{2}{\gamma}}} \right]} \begin{matrix} 1000.0 & 1180.0 & 1335.0 & 1465.0 & 1605.0 & 1617.0 \end{matrix}$$

$$.0437 \begin{matrix} 480. & 576.0 & 672.0 & 768.0 & 864.5 & 960.0 \end{matrix}$$

$$\frac{V}{C} \begin{matrix} .430 & .548 & .503 & .523 & .537 & .593 \end{matrix}$$



## TABLE XIV

## COMPUTED EFFICIENCY

1" DIAMETER RODS AT 3.0

| Run No.                                                                               | 26     | 28     | 30     | 29     | 27     | 25     |
|---------------------------------------------------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPM                                                                                   | 10,000 | 12,000 | 14,000 | 15,000 | 18,000 | 20,000 |
| $\eta_c$                                                                              | 76.0   | 84.4   | 86.7   | 89.5   | 97.8   | 103.2  |
| $T_{T2}$                                                                              | 527    | 530    | 532    | 530    | 530    | 527    |
| $C_p T_{T2}$                                                                          | 126.5  | 127.2  | 127.8  | 127.2  | 127.2  | 126.5  |
| $\frac{\Delta T_c}{T_{T2}}$                                                           | .1024  | .1510  | .2025  | .2450  | .3020  | .3660  |
| $L_c$                                                                                 | 933.0  | 1618.0 | 2240.0 | 2805.0 | 3755.0 | 4780.0 |
| $T_t$                                                                                 | 71.4   | 84.0   | 97.8   | 114.0  | 130.8  | 150.6  |
| $T_{T4}$                                                                              | 1772   | 1772   | 1772   | 1778   | 1772   | 1772   |
| $C_p T_{T4}$                                                                          | 482.0  | 482.0  | 482.0  | 484.0  | 482.0  | 482.0  |
| $1 - \frac{1}{P_{RT}^{\frac{\gamma}{\gamma-1}}}$                                      | .0415  | .0515  | .0605  | .0849  | .1028  | .1235  |
| $L_t$                                                                                 | 1427.0 | 2053.0 | 2855.0 | 4655.0 | 6480.0 | 8945.0 |
| $\eta_t$                                                                              | 63.4   | 77.4   | 77.6   | 52.5   | 57.8   | 53.5   |
| $C_p T_{T4} \left[ 1 - \frac{1}{P_{RT}^{\frac{\gamma}{\gamma-1}}} \right]$            | 20.0   | 24.8   | 29.2   | 40.9   | 49.5   | 59.6   |
| $224 \sqrt{C_p T_{T4} \left[ 1 - \frac{1}{P_{RT}^{\frac{\gamma}{\gamma-1}}} \right]}$ | 1000.0 | 1116.0 | 1210.0 | 1230.0 | 1573.0 | 1727.0 |
| $\frac{L_t}{L_c}$                                                                     | 1.530  | 1.270  | 1.270  | 1.630  | 1.720  | 1.960  |
| $\frac{\eta_t}{\eta_c}$                                                               | .830   | .916   | .895   | .587   | .597   | .525   |



TABLE XV  
COMPUTED EFFICIENCY

1" L RODS AT 2.00

| Run No.                                                                   | 31     | 33     | 35     | 36     | 34     | 32     |
|---------------------------------------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPW                                                                       | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $T_c$                                                                     | 77.0   | 82.9   | 85.4   | 88.4   | 94.5   | 101.2  |
| $T_{T2}$                                                                  | 560    | 542    | 535    | 550    | 542    | 540    |
| $C_p T_{T2}$                                                              | 129.7  | 130.2  | 131.0  | 132.1  | 130.2  | 129.7  |
| $\frac{\Delta T_c}{T_{T2}}$                                               | .1018  | .1440  | .1925  | .2365  | .2915  | .3520  |
| $L_c$                                                                     | 1015.0 | 1556.0 | 2150.0 | 2765.0 | 3590.0 | 4620.0 |
| $\eta_t$                                                                  | 70.8   | 87.7   | 101.0  | 116.2  | 130.0  | 146.8  |
| $T_{T4}$                                                                  | 1763   | 1772   | 1772   | 1772   | 1772   | 1810   |
| $C_p T_{T4}$                                                              | 479.0  | 482.0  | 482.0  | 482.0  | 482.0  | 494.0  |
| $1 - \frac{1}{P_{RT} \frac{8}{\pi}}$                                      | .0412  | .0540  | .0690  | .0852  | .1040  | .1232  |
| $L_t$                                                                     | 1397   | 2285   | 3360   | 4770   | 6575   | 8940   |
| $\eta_t$                                                                  | 72.7   | 68.0   | 63.9   | 58.0   | 54.5   | 51.3   |
| $C_p T_{T4} \left[ 1 - \frac{1}{P_{RT} \frac{8}{\pi}} \right]$            | 19.7   | 26.0   | 33.3   | 41.0   | 50.1   | 57.4   |
| $224 \sqrt{C_p T_{T4} \left[ 1 - \frac{1}{P_{RT} \frac{8}{\pi}} \right]}$ | 994.0  | 1142.0 | 1290.0 | 1434.0 | 1587.0 | 1722.0 |
| $\frac{L_t}{L_c}$                                                         | 1.26.0 | .576.0 | .672.0 | .765.0 | .864.5 | .969.0 |
| $\frac{L_t}{L_c}$                                                         | .432   | .503   | .521   | .535   | .545   | .550   |



TABLE XVI

COMPUTED EFFICIENCY

1/3 SECTION OF TAIL PIPE BLOCKED AT 9/16"

| Run No.                                                                             | 37     | 38     | 39     | 40     | 42     | 41     |
|-------------------------------------------------------------------------------------|--------|--------|--------|--------|--------|--------|
| RPM                                                                                 | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| $w_c$                                                                               | 76.7   | 86.0   | 93.3   | 99.0   | 100.6  | 98.5   |
| $T_{T2}$                                                                            | 520    | 520    | 520    | 522    | 525    | 525    |
| $C_p T_{T2}$                                                                        | 124.7  | 124.7  | 124.7  | 125.2  | 126.0  | 126.0  |
| $\frac{\Delta T_c}{T_{T2}}$                                                         | .1053  | .1536  | .2000  | .2545  | .3335  | .3715  |
| $L_c$                                                                               | 1010.0 | 1646.0 | 2175.0 | 2840.0 | 3800.0 | 4610.0 |
| $w_t$                                                                               | 71.3   | 86.6   | 101.1  | 115.0  | 130.5  | 156.5  |
| $T_{T4}$                                                                            | 1772   | 1772   | 1772   | 1764   | 1785   | 1764   |
| $C_p T_{T4}$                                                                        | 432.0  | 432.0  | 432.0  | 479.3  | 436.0  | 479.3  |
| $1 - \frac{1}{P_{RT}^{\frac{\gamma-1}{\gamma}}}$                                    | .0429  | .0590  | .0732  | .0878  | .1058  | .1208  |
| $L_t$                                                                               | 1430.0 | 2060.0 | 3570.0 | 4330.0 | 7670.0 | 9055.0 |
| $\eta_t$                                                                            | 63.2   | 66.8   | 60.9   | 53.8   | 49.5   | 51.0   |
| $C_p T_{T4} \left[ 1 - \frac{1}{P_{RT}^{\frac{\gamma-1}{\gamma}}} \right]$          | 20.6   | 23.4   | 35.3   | 42.0   | 51.5   | 57.9   |
| $4 \sqrt{C_p T_{T4} \left[ 1 - \frac{1}{P_{RT}^{\frac{\gamma-1}{\gamma}}} \right]}$ | 1015.0 | 1200.0 | 1330.0 | 1452.0 | 1608.0 | 1705.0 |
| $.0432$                                                                             | 430.0  | 576.0  | 572.0  | 763.0  | 864.5  | 960.0  |
| $\frac{L}{\eta}$                                                                    | .473   | .420   | .505   | .521   | .537   | .563   |



TABLE XVII  
EFFICIENCY BY CURVES

| RPM                                       | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
|-------------------------------------------|--------|--------|--------|--------|--------|--------|
| $\frac{1}{\sqrt{\theta_2}}$               | 9935   | 11878  | 13818  | 15760  | 17790  | 19828  |
| $\frac{\sqrt{\theta_2}}{\delta_2}$        | 94.0   | 113.0  | 132.3  | 152.0  | 173.2  | 217.0  |
| $\sqrt{\theta_2}$                         | 1.010  | 1.020  | 1.024  | 1.013  | 1.010  | 1.009  |
| $\delta_2$                                | .801   | .733   | .666   | .602   | .542   | .473   |
| $T_c$                                     | 76.0   | 81.7   | 87.4   | 90.4   | 95.3   | 102.0  |
| $T_{T2}$                                  | 529    | 531    | 532    | 534    | 532    | 529    |
| $C_p T_{T2}$                              | 127.0  | 127.5  | 127.7  | 128.2  | 127.7  | 127.0  |
| $\frac{\Delta T_c}{T_{T2}}$               | .1010  | .1502  | .1970  | .2420  | .3000  | .3700  |
| $L_c$                                     | 975.0  | 1560.0 | 2195.0 | 2800.0 | 3670.0 | 4785.0 |
| $\frac{1}{\sqrt{\theta_4}}$               | 5408   | 6403   | 7563   | 8650   | 9733   | 10775  |
| $\sqrt{\theta_4}$                         | 1.350  | 1.350  | 1.350  | 1.350  | 1.350  | 1.350  |
| $\delta_4$                                | 1.150  | 1.212  | 1.307  | 1.414  | 1.516  | 1.640  |
| $\frac{\sqrt{\theta_4}}{\delta_4}$        | 112.0  | 130.0  | 144.5  | 155.0  | 161.5  | 166.5  |
| $T_t$                                     | 69.6   | 85.1   | 102.0  | 117.6  | 132.0  | 149.5  |
| $T_{T4}$                                  | 1770   | 1772   | 1772   | 1772   | 1776   | 1778   |
| $C_p T_{T4}$                              | 401.2  | 402.0  | 402.0  | 402.0  | 403.4  | 404.0  |
| $1 - \frac{1}{r_{t4} \frac{1}{\delta_4}}$ | .0400  | .0262  | .0702  | .0896  | .1030  | .1132  |
| $L_t$                                     | 1346.0 | 2150.0 | 3460.0 | 5140.0 | 6560.0 | 8550.0 |
| $\eta_t$                                  | 72.5   | 72.5   | 63.5   | 54.5   | 55.9   | 56.0   |



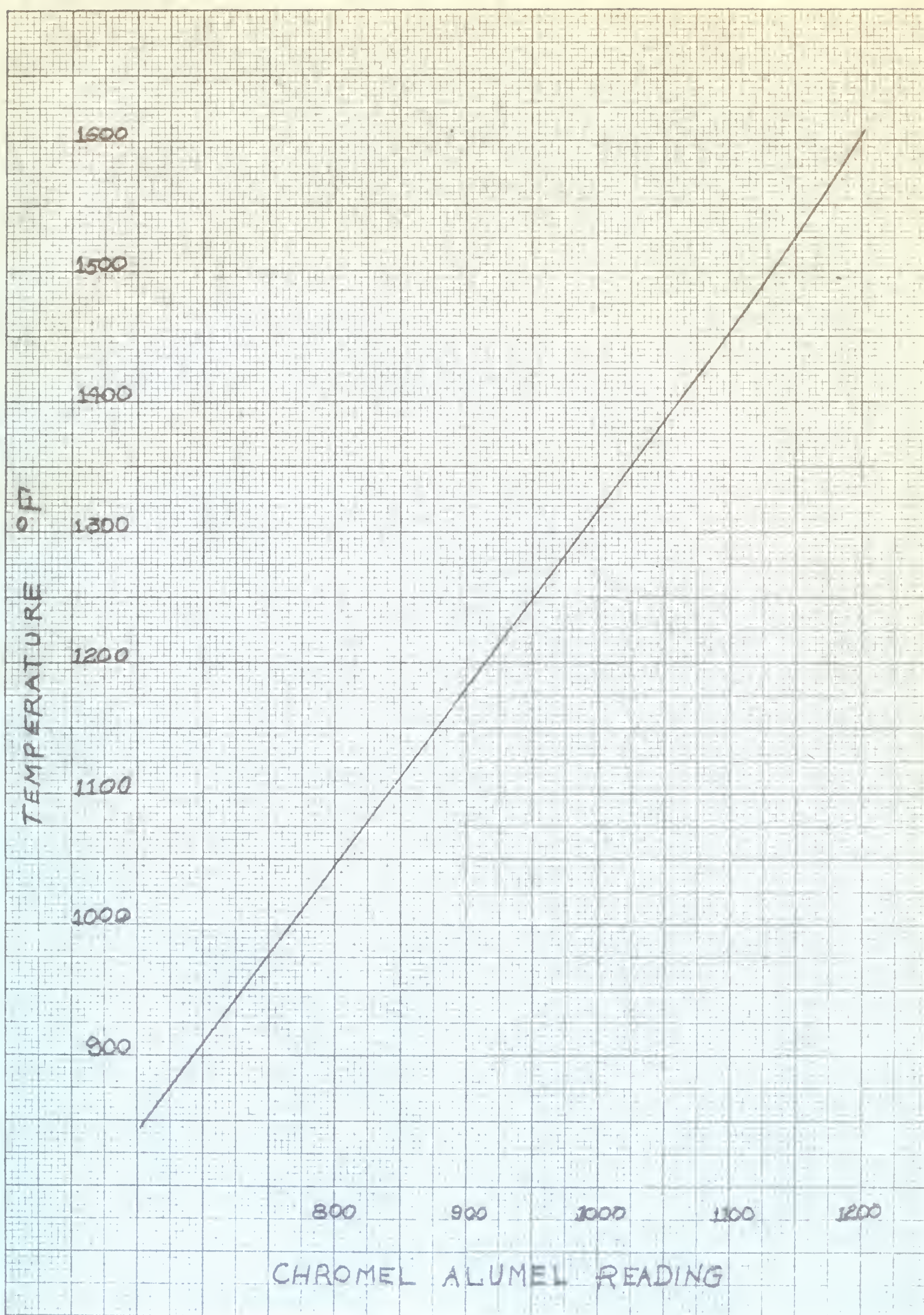
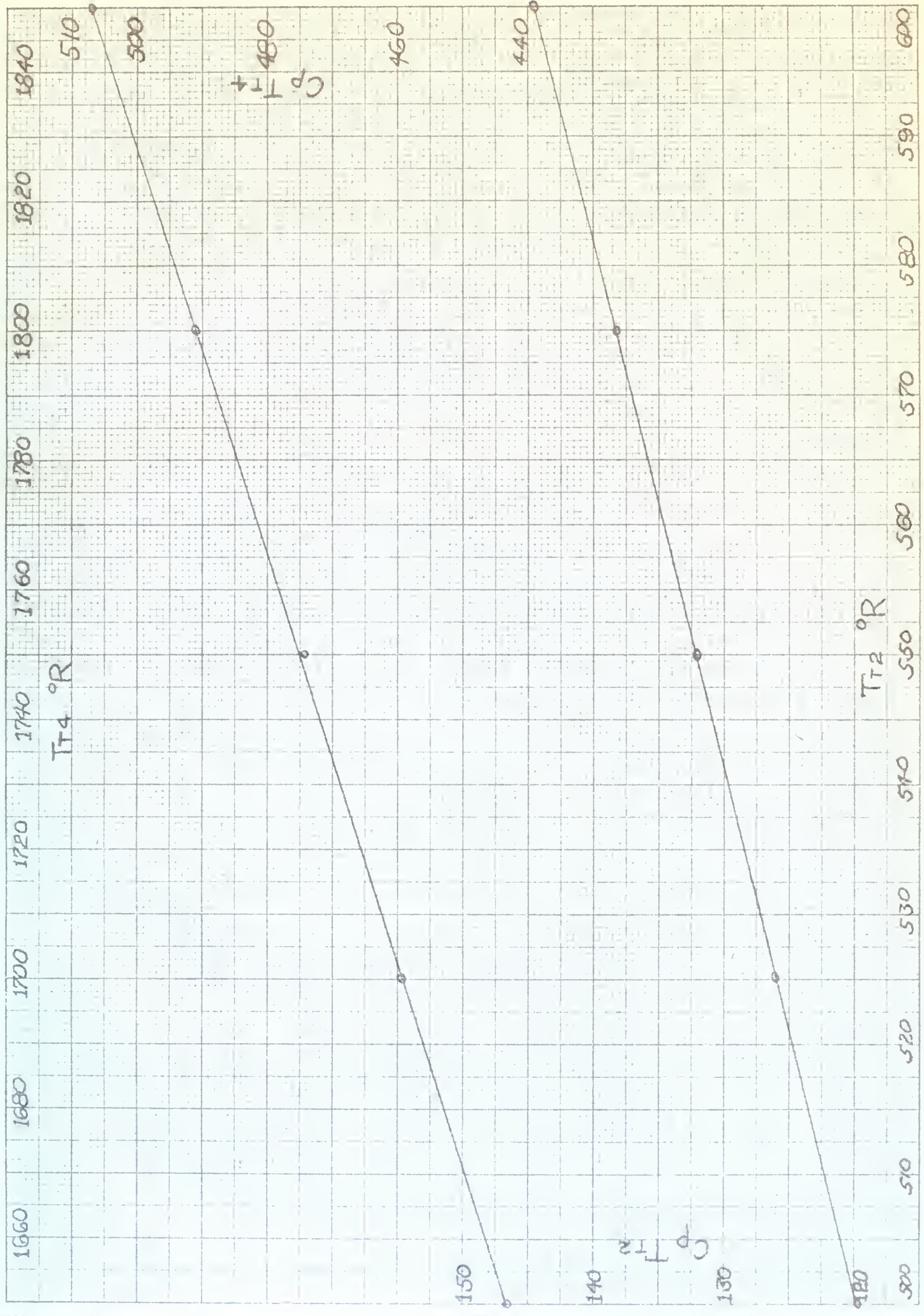


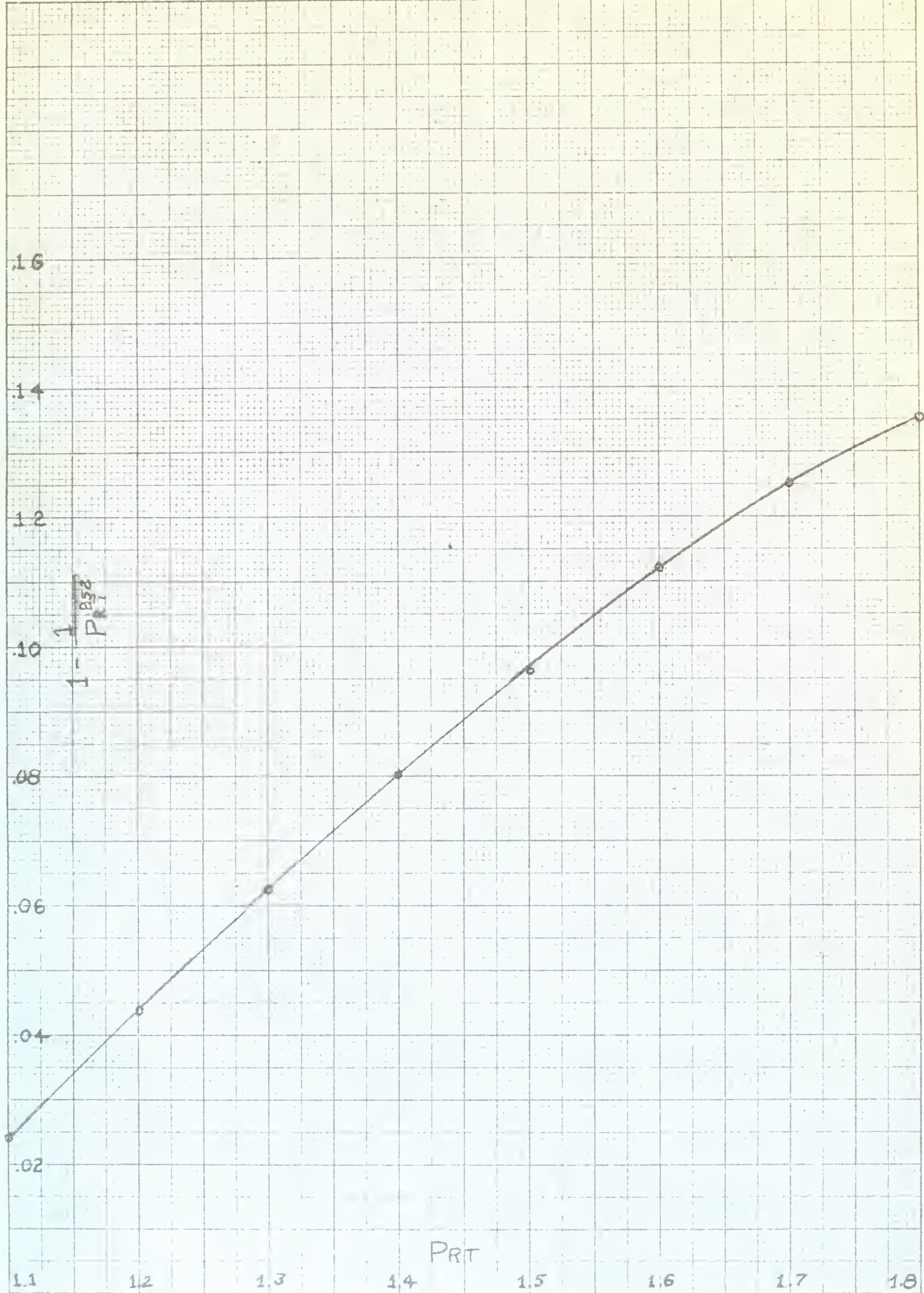
Fig. 1

Chromel Alumel Calibration

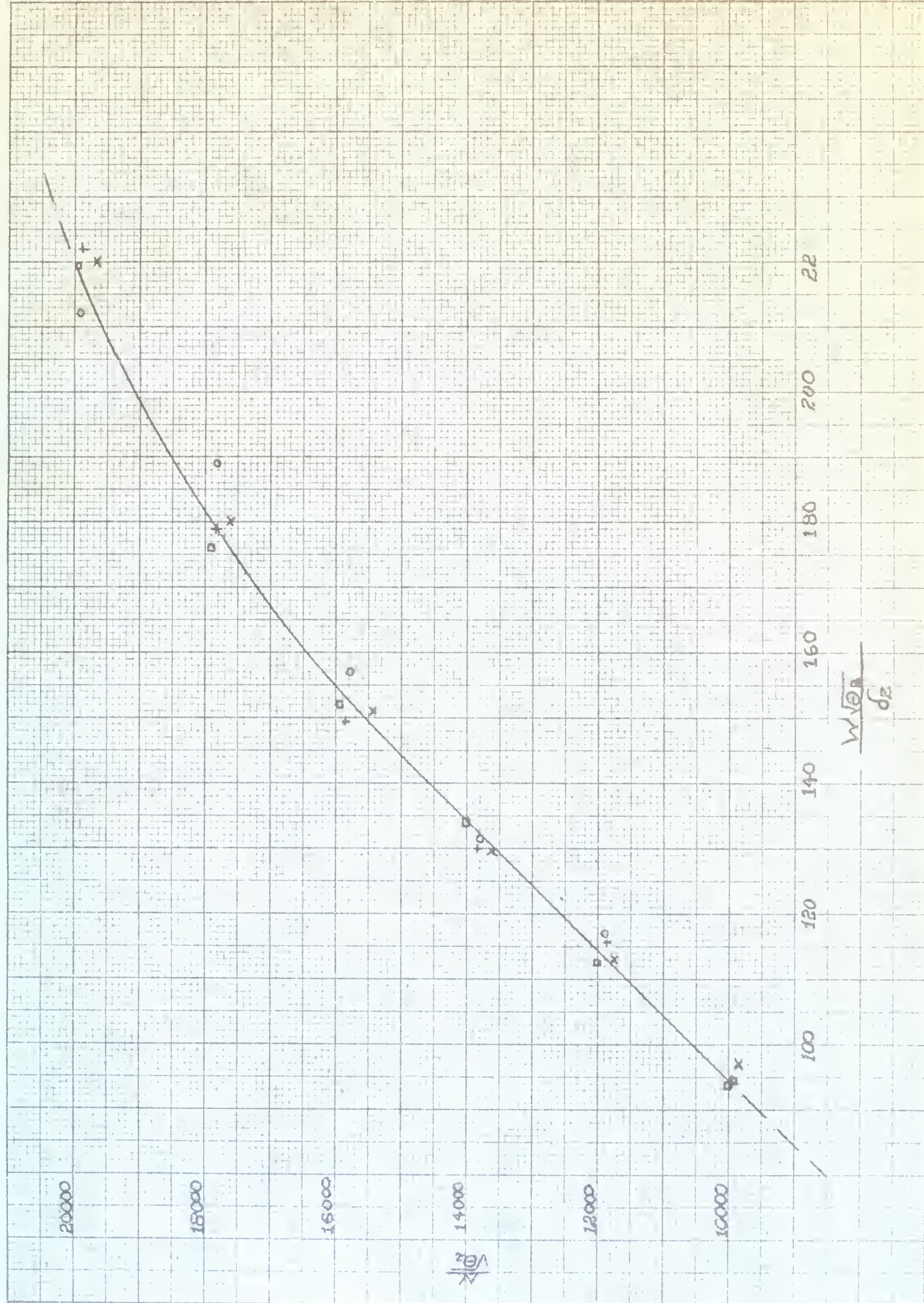




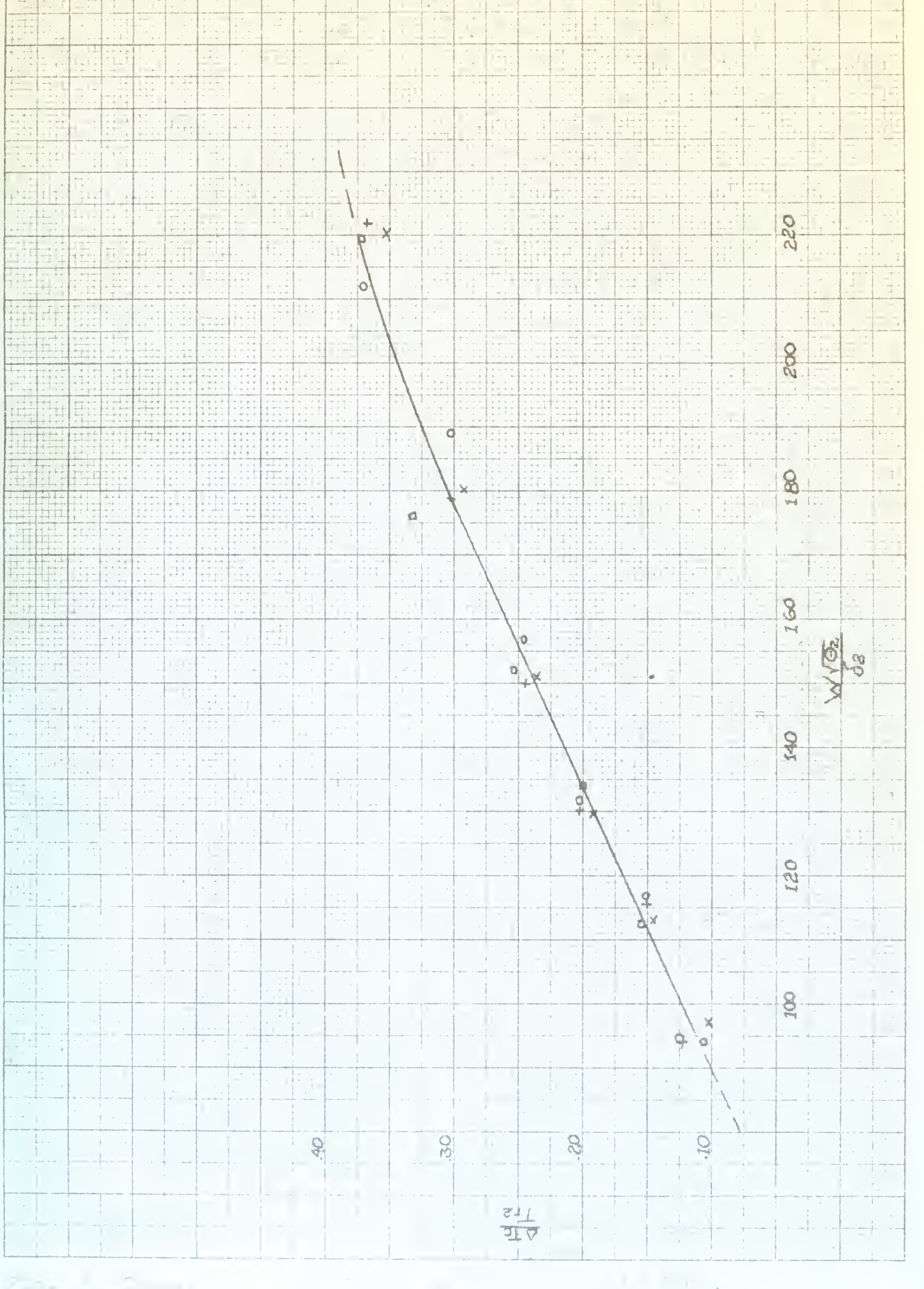














1.0

.9

.8

.7

.6

.5

.4

$\sigma_p$

100

120

140

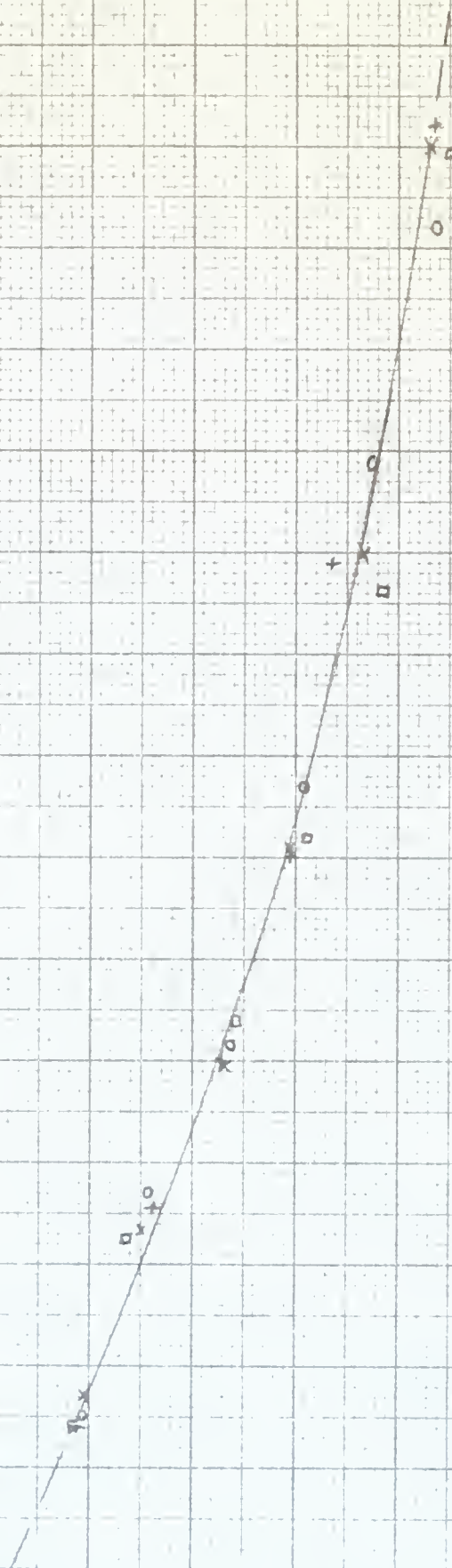
160

180

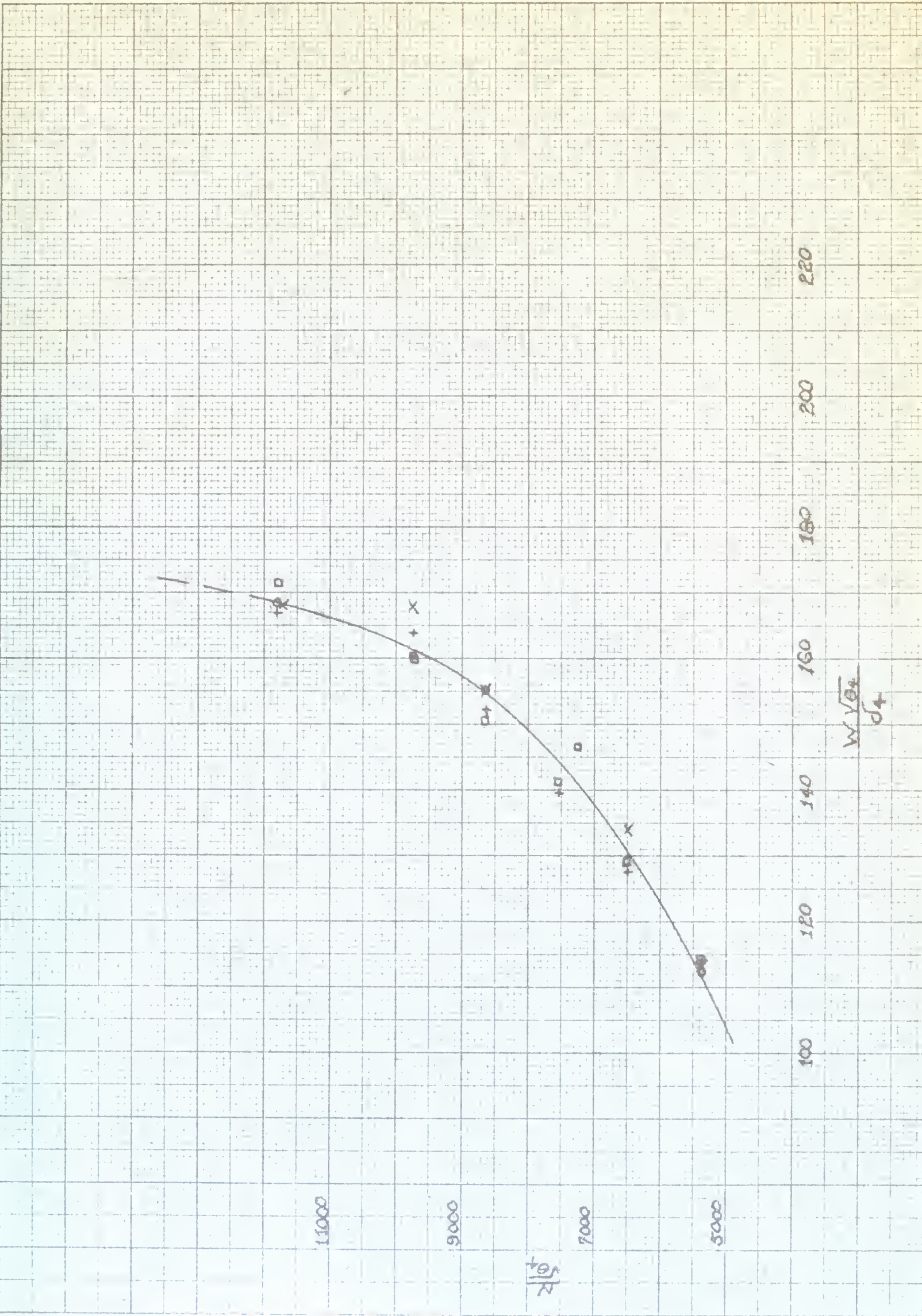
200

220

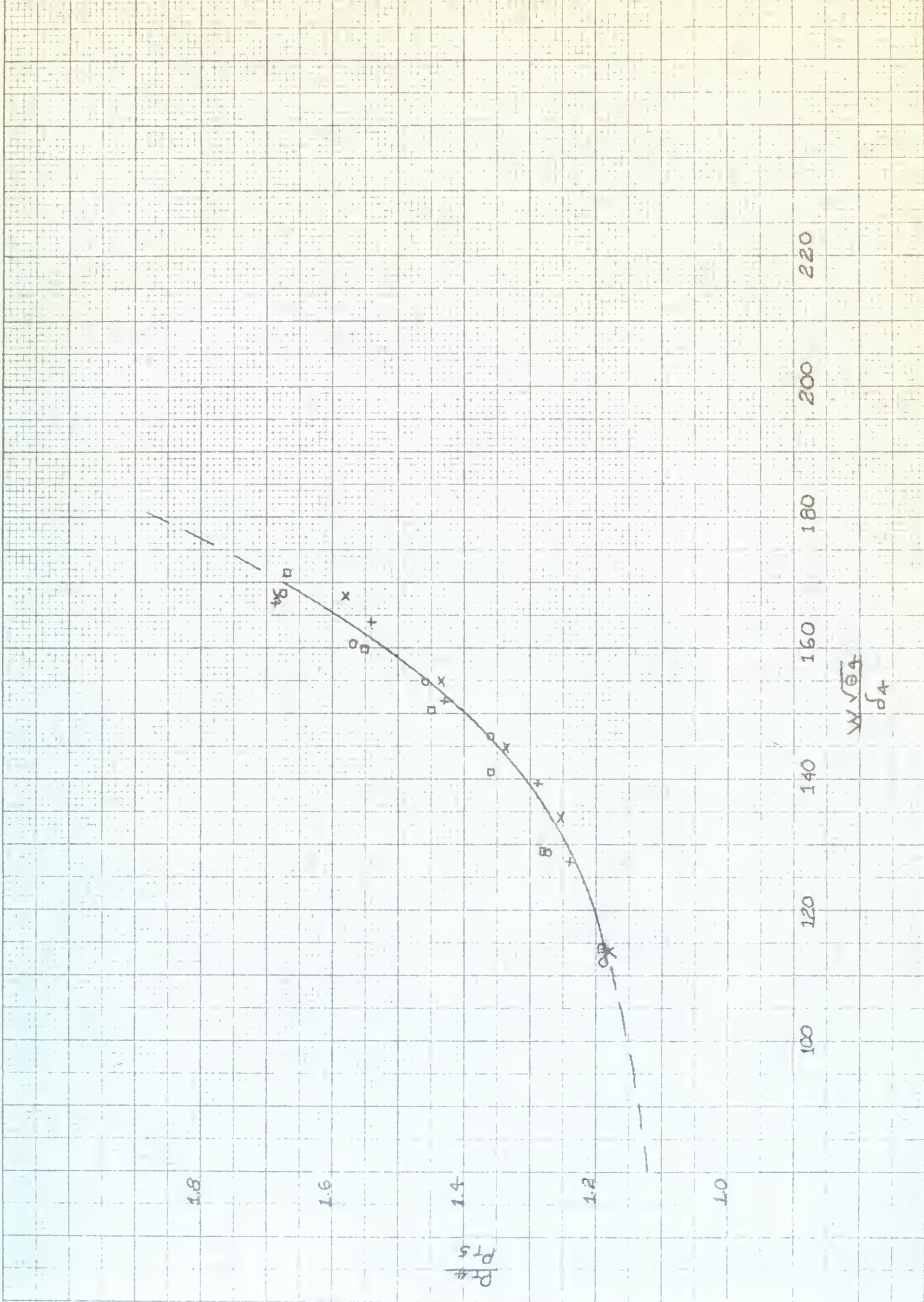
$\frac{W\sqrt{\sigma_1}}{\sigma_2}$



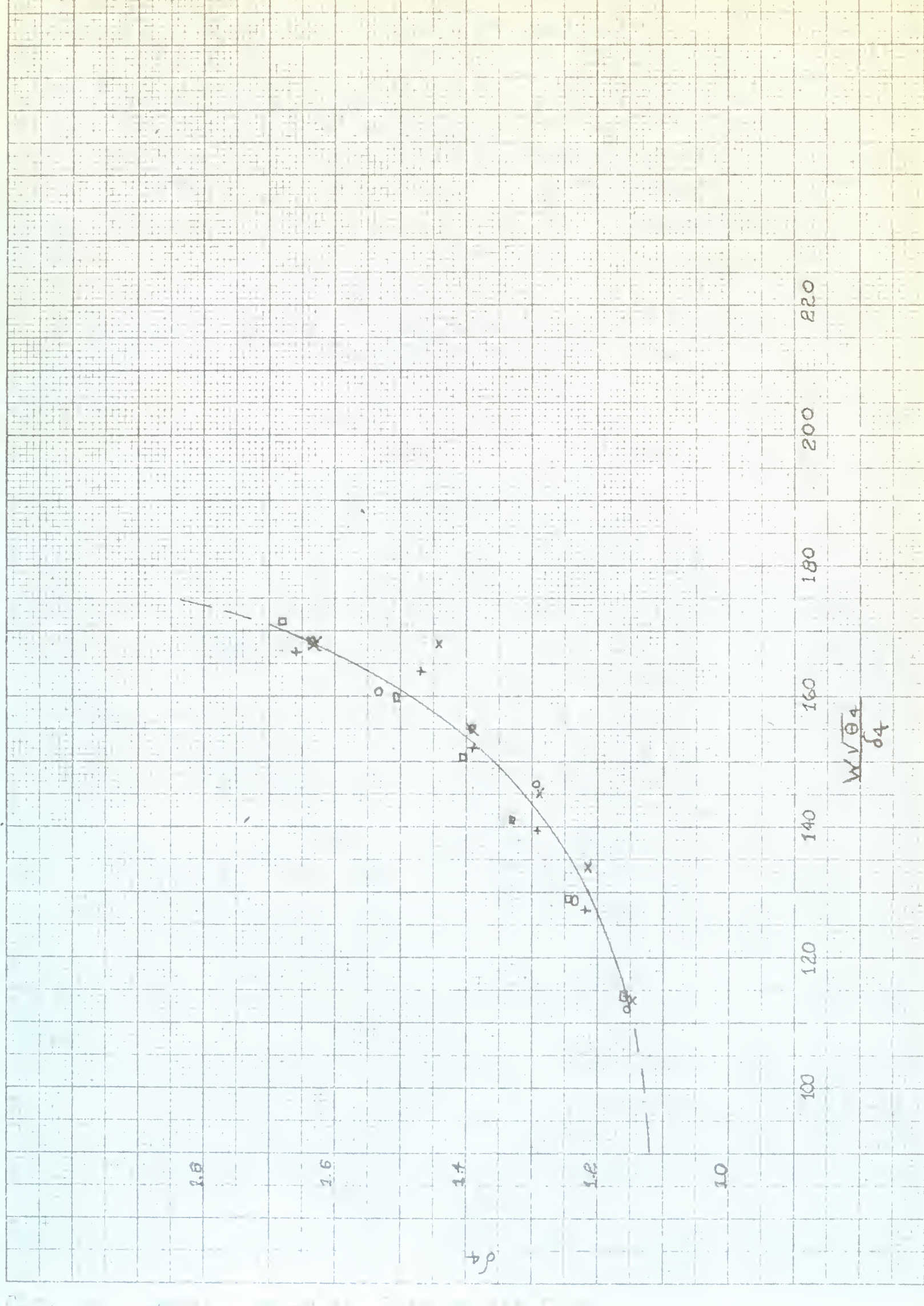












$$\frac{W\sqrt{\theta_4}}{\delta_4}$$







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